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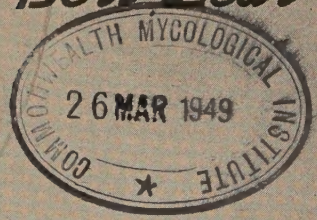
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Soil Fumigation

For Nematode and Disease Control

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September, 1948

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The diagram of a plow applicator shown on page 17 is from Soil Fumigation with Dofume W-40 (Tech. Agr. Bul. Ser. No. 5, 1947, Dow Chem. Co., Midland, Mich.)

SOIL FUMIGATION

For Nematode and Disease Control

By A. G. Newhall and Bert Lear

Why Fumigate Soils

Hothouse vegetable growers, florists, nurserymen, truck-growers, market gardeners, and others who try to grow plants sooner or later encounter one or more soil-infesting pests which prevent seedling emergence, reduce vigor, cut yields, or prevent profits and satisfaction from their labors. Sometimes these losses can be avoided by changing the soil or by crop rotation. In greenhouses the soil has been steamed for the past fifty years, primarily for the control of the root-knot nematode *Heterodera marioni*. Steaming is expensive and is not feasible for many growers. How best to control damping-off, weed seeds, wireworms, or nematodes has become the perennial question with many growers of all kinds of crops.

During the past 10 to 20 years a number of cheap, volatile, liquid, chlorinated hydrocarbons, capable of killing some of these pests, have been developed in sufficient quantity to show great promise. It is now possible to treat large outdoor areas infested with nematodes or wireworms at a cost which most good vegetable land can justify. Some liquid fumigants can kill nematodes, fungi, insects, and weed seeds, but the cheaper ones at present are mainly nematocides and insecticides. Fumigants kill by means of volatile fumes which diffuse several inches through the soil around the point of injection. Since most of them contain substances toxic to plant life, they are applied before the crop is sown, and usually a period of from 1 to 20 days must elapse to permit escape of the toxic fumes before planting can safely be done after treatment.

The Principal Fumigants Available

A great many volatile chemicals have been and still are being tested. Most of the better ones contain either chlorine or bromine. It is still not known, however, why one chemical is so effective while another closely related one is worthless.

The fumigants most useful to New York growers at present include the following, in alphabetical order: chloropicrin (trichloronitromethane), sold either as such or as "Larvacide"; mixtures of dichloropropane and dichloropropene sold as "DD mixture" or "Dowfume N"; ethylene dibro-

mide mixtures (dibromoethane) of several strengths, sold under such trade names as "Garden Dowfume," "Dowfume W-40," "Iscombrome D," "Bromofume," and "Soilfume"; and lastly, methyl bromide (bromoethane) either pure or in solution, sold under such trade names as "Dowfume G," and "Iscombrome." Table 1 gives the essential composition and sources of most of those on the market, some of which are marketed at present only on the West Coast.

Table 1. Some available soil fumigants

Active ingredient	Approximate concentration by volume (per cent)	Trade Name	Some Sources
Chloropicrin	100	Larvacide	Innis, Speiden & Co.
Chloropicrin	100		Dow Chemical Co.
Dichloropropenes*	50	DD mixture	Shell Chemical Corp.
Dichloropropenes*	50	Dowfume N	Dow Chemical Co.
Ethylene dibromide†	5	Garden Dowfume	Dow Chemical Co.
Ethylene dibromide†	5	Bromofume 10	Eston Chemicals, Inc.
Ethylene dibromide†	10	Bromofume 20	Eston Chemicals, Inc.
Ethylene dibromide†	10	Iscombrome D	Innis, Speiden & Co.
Ethylene dibromide†	10	Soilfume 80-20	Westvaco Chlorine Products Corp.
Ethylene dibromide†	20	Soilfume 60-40	Westvaco Chlorine Products Corp.
Ethylene dibromide†	20	Bromofume 40	Eston Chemicals, Inc.
Ethylene dibromide†	20	Dowfume W-40	Dow Chemical Co.
Methyl bromide‡	10	Dowfume G	Dow Chemical Co.
Methyl bromide‡	15	Iscombrome	Innis, Speiden & Co.

* Contains large proportion of 1,2 dichloropropane and some higher-boiling trichlorides.

† Diluent, some cheap naphtha in most instances.

‡ Diluents may be carbon tetrachloride, ethylene dichloride, and propylene dichloride in Dowfume G, and xylene in Iscombrome.

Chloropicrin

The bactericidal and fungicidal properties of this chemical, better known as *tear gas*, were thoroughly investigated in Europe after World War I when large stocks were left over. When injected into soil it was found to be an effective control for root-knot nematode of pineapple in 1934. It has been much used to kill nematode, insects, fungi, and weed seeds. It has therefore been a yardstick by which fumigants have been measured for the past 10 years. No other fumigant at present surpasses it in fungicidal properties, pound for pound, although under gastight confinement, methyl bromide may equal it on a cost basis. The technical name of chloropicrin is trichloronitromethane— CCl_3NO_2 . It is a heavy practically colorless to pale yellowish liquid, weighing 1.65 times as much as water, which means that a pound contains only 274 ml instead of 453. Its boiling point is about 112°C , and it vaporizes readily at room temperatures, leaving no residue. The vapor has a sweetish, pungent odor, which quickly causes tears to flow, and nausea follows the breathing of even low concentrations. The effect on the tear ducts is considered a

safety feature in the fumigation of mills, warehouses, boxcars, etc., since man cannot endure for many minutes a concentration far below the minimal lethal one. Chloropicrin, like the other fumigants discussed here, is not inflammable in either the liquid or vapor state. Since carbon disulfide is very inflammable, and makes some workers ill, no further mention of this fumigant will be made.

Chloropicrin has three drawbacks that limit its usefulness. One is its expense, due largely to the high cost of manufacture and to its nitrogen content. Another is its phytocidal property; that is, the vapor kills foliage and flowers as well as the roots of living plants. This is what makes it so effective in eradicating many weed seeds from soil, but it also necessitates the removal of all growing plants from that part of the greenhouse that is to be fumigated. The third drawback is its corrosive action on metals and human skin.

To keep the dosage rate and cost as low as possible and to insure better kill near the soil surface, it is essential to use some sort of a seal immediately after applying chloropicrin to prevent the gas from escaping too soon. Since it is practically insoluble in water, the use of a water seal (sprinkling of the soil surface with from 1 to 2 pints of water per square foot) has become a universal practice among greenhouse growers and gardeners. This limits its economical use to places where water and some sort of sprinkler system are available. For small areas or piles of soil, gas-proof tarpaulins, glue-coated paper, or gastight containers are satisfactory covers. Chloropicrin is marketed in 1-pound bottles, and in steel cylinders of various sizes. A gas mask is sometimes used in greenhouses, but is not always essential if filling of applicators and their calibration is done outdoors in a slight breeze.

Mixtures of Dichloropropanes and Dichloropropenes

During World War II, allyl alcohol was made in large quantities as one step in the manufacture of plastics from petroleum. A by-product of this process contains approximately two-thirds dichloropropenes, one-third dichloropropane, and a small proportion of higher-boiling trichlorides. In 1943 it was announced, in Hawaii, that this by-product, called "DD mixture," was as effective as chloropicrin in destroying root-knot nematode in pineapple fields, and at less than one-fourth the cost per pound. Later, in California, a still lower dosage rate was proved to control wireworms.

The propane-propene mixtures, sold as "DD mixture" and "Dowfume N," are slightly oily, brownish-liquids, about one-fifth heavier than water, and one pound contains approximately 384 ml. They boil over a temperature range from 95° to 150°C, are completely volatile, noninflammable, and have a pungent, sweetish, and somewhat nauseating odor. They can cause burning of the skin after some minutes of contact, especially under the fingernails. In the presence of moisture they can be rather cor-

rosive to metals; applicators should never be rinsed with water, but rather with gasoline or fuel oil. Tests have shown that 1,3 dichloropropene is effective against nematodes, whereas 1,2 dichloropropane is not. Hence manufacturers are trying to step up the proportion of propene in their products.

Although less disagreeable to handle than chloropicrin, and much cheaper, the propane-propene mixtures do not kill as large a variety of pests, and they have very little effect on fungous diseases. However, their ability to linger and kill nematodes and insects in the upper layers of the soil without benefit of water or other seal makes them very useful in the treatment of vast areas or root-knot and wireworm-infested soil where water is unavailable or its use not feasible. Although they are not particularly good herbicides at the minimal dosages of 20 to 40 gallons an acre recommended for nematodes and wireworms, a good many weed seeds can be killed if soil conditions have been specially favorable for their germination just before treatment. Their use in certain sections of the country has brought back into profitable production many thousands of acres of land heavily infested with root-knot nematodes and wireworms, but otherwise good soil.

The vapor of propane-propene mixtures may be rather disagreeable in a greenhouse for a few days after soil treatment, but it is not particularly injurious to flowers or foliage of most plants so far tested if a reasonable amount of ventilation can be provided. More research on this is necessary however. Soil has been treated successfully for nematodes at temperatures in the low 50's (F), and the penetrating qualities of these fumigants in unrotted galls are somewhat better than chloropicrin. However, in soil as cold as this, two or more weeks may have to elapse before it is safe to set in some plants. Therefore, in northern greenhouses, summer treatments are preferable to winter ones.

Fumigants Containing Ethylene Dibromide

Several soil fumigants on the market at present contain various proportions of this odorless noninflammable, noncorrosive, insoluble, volatile hydrocarbon, which has nearly the same lethal properties for nematodes and wireworms that the propane-propene mixtures have. Garden Dowfume and Bromofume contain 5 per cent ethylene dibromide; Bromofume 20, Iscobrome D, Soilfume 80-20, 10 per cent; and Bromofume 40, Dowfume W-40, and Soilfume 60-40 contain 20 per cent of the active ingredient. All are dissolved in a suitable cheap, harmless, volatile solvent, which is usually a naptha. The solvent may of itself be something of a fire hazard.

Although not much good as fungicides or herbicides at present, these fumigants are among the cheapest soil nematocides and insecticides now available. The boiling point of ethylene dibromide is 20°

above that of chloropicrin, and so it will persist in the soil a little longer. Like the propane-propene mixtures, these fumigants do not require a water seal and hence are very useful in field control of nematodes and wireworms. In a Rochester, New York, greenhouse in 1946, tomatoes set in soil 8 days after treatment with a 10 per cent product did not all survive, but all those set after 15 days survived. Soil temperature was 72°F. Ethylene dibromide mixtures are not disagreeable to handle, nor are they corrosive to metal, which makes them more satisfactory in these respects than either chloropicrin or the propane-propene mixtures. However, as with all the fumigants discussed, the vapor should not be breathed any more than can be helped. Plenty of ventilation should be provided the operator at all times.

Methyl Bromide

The very active, volatile, lethal properties of this chemical have given it, during the past 10 years, a high place as a space fumigant to eliminate various insect pests from stored food products. It has also been extensively used to fumigate nursery stock to eliminate many kinds of insect pests. Its usefulness as a soil fumigant for nematodes has been thoroughly demonstrated for the past 6 or 8 years. At ordinary temperatures, above 43°F, methyl bromide is a colorless, odorless gas. It has to be marketed in sealed cans or steel cylinders or dissolved in a cheap solvent to keep it in the liquid condition. The two trade-named soil fumigants containing 10 and 15 per cent methyl bromide respectively in such harmless, nearly odorless solvents are Dowfume G and Iscobrome. The latter has a specific gravity practically the same as that of water, meaning that a pound contains 456 ml; the former weighs more than water, and a pound contains but 329 ml.

Methyl bromide can be used in soil within a foot of many growing plants without injury to their roots. One of the remarkable characteristics of this chemical is its penetrating power and speedy action. It has been known to kill nematodes, in large unrotted tomato root galls imbedded in treated soil, in less than an hour. Soil so treated has been safely sown two days after treatment, and seedlings or tomato plants set out in 5 days. It goes without saying that such a fumigant must be sealed in promptly. A water seal of from 1 to 2 pints per square foot of soil, as for chloropicrin, is commonly employed on greenhouse benches or in groundbeds.

The speed with which methyl bromide mixtures leave the soil recommends them for winter use in greenhouses where soil temperatures are below 65°F, especially when economic conditions dictate that the soil should not be left idle for more than 7 to 10 days. Being noncorrosive, they are easily used in several of the fumigant dispensers on the market without excessive wear and tear.

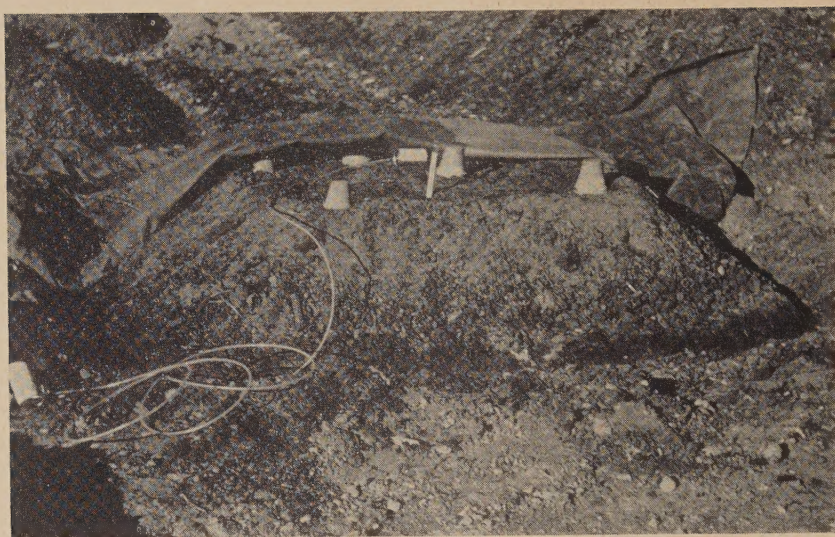


Figure 1. Method of treating compost pile of 1 cubic yard with a 1-pound can of liquid methyl bromide under a gastight tarpaulin. Flower pots provide air chamber between soil and the cover. Soil can be treated successfully at temperatures above 50°F.

Although their chief use is against the root-knot nematode, methyl bromide fumigants, like chloropicrin, can be used to destroy fungi in small quantities of soil which can be held in a gastight chamber or covered with gasproof paper or cloth for a few hours (figures 1 to 5).

Only a little less expensive than chloropicrin, these fumigants find their greatest usefulness in the treatment of seedbeds, potting soil, benches, and ground beds of greenhouses. The necessity of a water or other seal limits their extensive field use. Since this material is very toxic to man, extreme care should be taken in its use. Several fatal accidents from its use in fumigation of elevators and boxcars have been recorded in the literature.

How to Treat Small Quantities of Soil

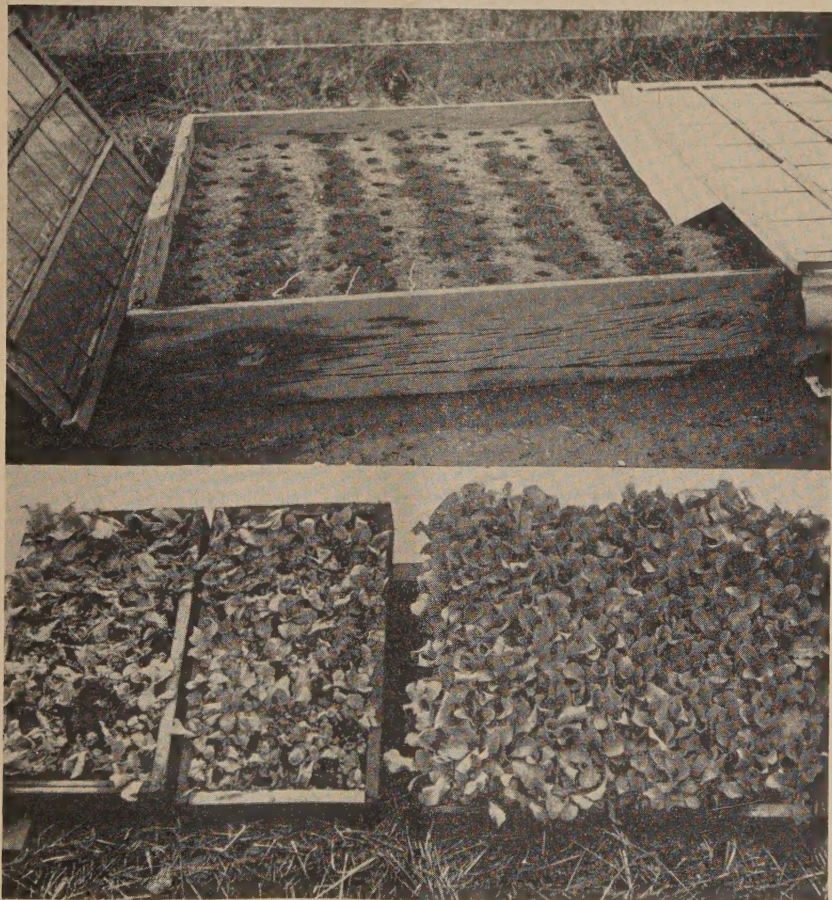
Soil for potting purposes, seed flats, or cutting benches can be treated to eliminate damping-off fungi, weed seeds, or nematodes with either chloropicrin, methyl bromide, or one of the methyl bromide fumigants (Dowfume G, or Iscobrome). Such soil can be placed in a metal drum, tight barrel, box, bin, in flats, or just in a pile on a tight floor. If peat moss or manure is to be added to the soil, it should be done before fumigation is begun.

If the soil is outdoors in a pile, a gastight tarpaulin makes a good cover. (figure 1). These can be purchased of any size or shape for

approximately 10 cents a square foot.¹ Glue-coated paper also can be used and is excellent for covering seedbeds, coldframes, and raised benches, or the end of a barrel, box, bin or drum (figure 2). It comes in rolls of various widths and, with care, can be used several times. Any ordinary waterproofed tarpaulin is of no value in retarding escape of fumigants from soil (figure 3). A plain wet canvas is lightly sprinkled with water at frequent intervals for 6 hours is satisfactory

Figure 2. Upper: a coldframe prepared for treatment, with 1 pound of methyl bromide per cubic yard of soil, by punching holes every 8 inches, and covering with glue-coated paper. *Sclerotia*, moistened for a few hours beforehand, tied to the ends of the 3 white strings, and buried 3, 6, and 9 inches deep, were all killed.

Lower: lettuce growing in Dowfume-G-treated (right), and untreated (left) sandy loam soil. Treatment rate was 50 ml per cubic foot of soil at 55°F, under gasproof tarpaulin; soil in layer 1 foot deep on concrete floor. (February 19, 1947.)



¹ Names of manufacturers given on request.



Figure 3. Fumigation of compost piles for nematode, weed, and damping-off control with chloropicrin or methyl bromide is feasible if a gasproof cover is used. Above, testing different types of cover. Below, stands of seedlings grown in (A) soil fumigated with methyl bromide held under waterproof canvas, (B) under gasproof canvas, (C) untreated. Treatment rate was 1 pound per cubic yard at 53°F.

if several layers of wet newspapers, wet peat moss, or burlap sacks, or several thicknesses of cloth-house cloth are laid down first.

Soil should be loose, moist enough for good seed germination, and between 50 and 85°F. It should also be moistened several days before treatment to encourage swelling and cracking of weed-seed coats. The temperature should be 60°F or higher if "Larvacide" is employed, and above 50° if methyl bromide is used. The dosage rate for chloropicrin may well vary between $\frac{1}{2}$ and 1 pound per cubic yard of soil (5 to 10 ml per cubic foot) depending on lightness of soil, tightness of the cover, and soil temperature. Warm sandy soil in metal drums does not require as large a dose as does cool, heavy soil in a pile under wet canvas out in the wind. The dosage for straight methyl bromide in a barrel or tight bin is from 5 to 10 ml per cubic foot, depending on

temperature, or 25 to 50 ml of Iscobrome or Dowfume G per cubic foot.

Flats

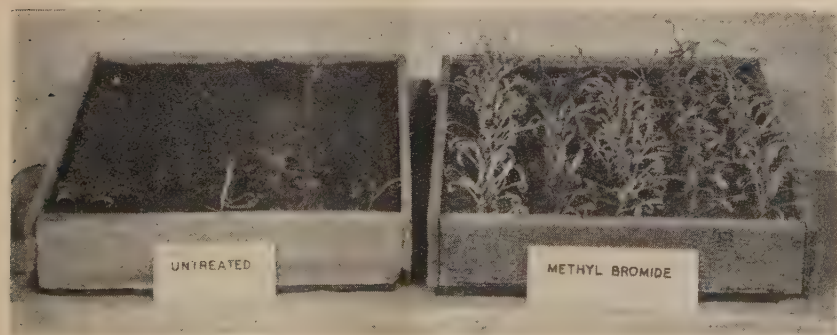
If soil is screened into flats up to 14 X 22 inches in size, chloropicrin can be injected to half the depth of the soil in 4 evenly spaced holes, using 1 to 1½ ml per injection. Iscobrome or Dowfume G can also be employed in the same manner at 4 to 6 ml per injection. Holes must immediately be closed and tamped. Flats should immediately be sprinkled, piled, and covered with a wet or gasproof covering. Over night is a long enough time to leave soil treated with methyl bromide mixtures, but 3 days is recommended when chloropicrin is used. Soil treated with chloropicrin should be aired until all odor has left it.

Potting Soil

Many growers prefer to have a stock pile of soil treated in advance. For this a bin or a series of barrels or drums can be used. Soil is placed to a depth of a few inches in a 50-gallon drum (5 bushels or 8 cubic feet), and a third of the required fumigant poured over it; another foot of soil is added and the second third poured on; this is repeated until the drum is full. The top is moistened and covered for 3 days, or 6 hours, depending on whether chloropicrin or a methyl bromide fumigant is being used, and on whether soil temperature is down to 60° or up above 75°F. Liquid methyl bromide can be dispensed from a can or cylinder, by means of suitable devices now available, and used at 5 to 10 ml per cubic foot of soil (figure 4).

Soil in a bin or piled on a concrete floor or in a deep frame can be treated by injecting the fumigant 5 or 6 inches deep in each 1-foot layer in holes spaced 8 to 12 inches apart. The dosage rate for chloropicrin is 7½ to 10 ml per cubic foot, and for Iscobrome and Dowfume

Figure 4. Sandy loam on right was treated in a 55-gallon metal drum with 90 ml of liquid methyl bromide (12 ml per cu. ft. of soil) at 48°F, and left for 8 days. In a later test, 3 hours was found to be a long enough exposure period.



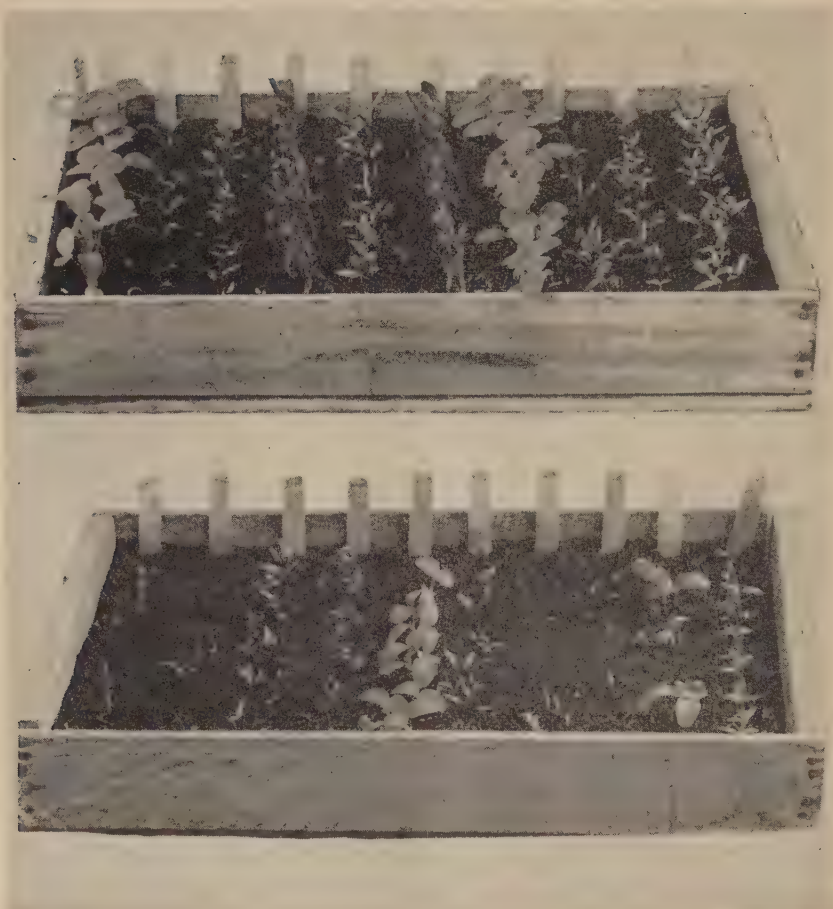


Figure 5. Soil in upper flat was from large pile of sandy loam potting soil treated with Dowfume G under gastight tarpaulin for 2 days on concrete floor at 53°F. Fumigant applied with Mack injector at rate of 60 ml, on 10-inch centers. Soil in lower flat untreated. Weeds in two flats of treated soil were 72 and 101, all clover; in two flats of untreated soil there were 224 and 237 weeds, representing many different types.

G, 25 to 50 ml, depending largely on soil temperature and efficiency of the confinement. The lower the temperature the more is required (figure 5).

Soil in piles of one cubic yard has been successfully treated by liberating a pound of methyl bromide under a gasproof tarpaulin laid loosely over the pile to leave a slight air space. The margins must be buried several inches in the soil all around. Methyl bromide can be bought in 1-pound cans or in different-sized cylinders. A special puncturing device with a 15-foot piece of flexible translucent "Saran" tubing attached is an aid in safely liberating the gas from cans. The

pile of soil should be loose, above 50°F, and poked full of holes with a broomstick. The delivery end of the Saran tubing should not be directed against the tarpaulin but should be in the soil or in another can (figure 1).

A coldframe soil can be treated in a manner similar to that shown in figure 2, or one of the methyl bromide mixtures can be injected at 25 to 50 ml per cubic foot, or chloropicrin at 7 to 10 ml per cubic foot. With these heavy dosages, from one to three weeks should elapse before the soil is used, and chloropicrin-treated soil should be turned over once or twice, unless treatment is done in the fall and the soil allowed to rest over winter. In any event, all odor of chloropicrin should be gone before soil is used for plant growing.

How to Treat Soil in Greenhouse Benches and Ground Beds

Benches can be freed from nematodes by treatments with any of the following fumigants. Injections should be spaced 10 inches apart and made to one-half the depth of the bench when the soil is loose, slightly moist, and above 60°F. *Chloropicrin* at 2.5 to 3.5 ml per injection should be used only when the house is entirely empty of living plants. Soil must be promptly sprinkled to a depth of 1 inch, or some other seal applied, such as a gastight tarpaulin, glue-coated paper, wet peat moss, or canvas, and should be sprinkled frequently for a day or two if only a water seal is employed. Enough time should elapse, 7 to 14 days, before seed is sown or plants are set in treated soil to permit escape of all odor of chloropicrin. *Methyl bromide* mixtures are used in the same manner, but the dosage rates must be from 5 to 7 ml per injection. Living plants do not have to be removed from the vicinity of the bench to be treated, and the soil may be planted in 4 to 8 days.

Ethylene dibromide and dichloropropene fumigants (Dowfume W-40, Iscobrome D, DD mixture, and Dowfume N, Soilfume, or Bromofume) can be used when only nematodes are being fought and soil is not needed again for from 8 to 18 days. The dosage rate of a 10 per cent (by volume) ethylene dibromide mixture or for DD mixture or Dowfume N should be 2 to 3 ml on 10-inch centers. No water or other seal is needed, although its use is believed to improve the retention and lethal action about 10 or 15 per cent. Most plants need not be removed from the vicinity while treatment is going on if plenty of ventilation is provided; however, all flowers have not been tested in this regard, and caution is urged. Double-strength mixtures such as Dowfume 40 should be used at half the above dosage rates; half-strength ones, at double the amount. Soil should not be sown until all odor of the fumigant has left, which may take from 8 to 15 days.

If fungi and weed seeds rather than nematodes are the chief pests being fought, only chloropicrin or the methyl bromide fumigants are

recommended, and then at greatly increased dosage rates of 7 to 8 ml on 10-inch centers for chloropicrin, and 25 to 50 ml for the methyl bromide mixtures. Heavy clay soils require higher dosage rates than do light sandy ones. Soil should be thoroughly watered a few days in advance to induce seeds to swell before treatment. Those with hard seed coats, such as the clovers, are very resistant to all fumigants (figure 5).

In ground beds the principal need for treatment of greenhouse soil is root-knot nematode control. For this purpose any of the fumigants mentioned are effective when properly used, but the methyl bromide ones are the best to use in winter or whenever soil temperatures are below 65°. Under cooler soil conditions the other fumigants may take too long to leave the soil, for greenhouse growers who must replant as soon as possible. Some growers are now treating with chloropicrin in the summer and with a methyl bromide mixture in winter. Even two fumigations a year are cheaper and require less labor than does one steaming, although they do not control diseases as well. When diseases are not a problem, a fumigant containing ethylene dibromide or dichloropropene can be used in the summer or whenever soil temperatures are above 70°F. Soil should be spaded, forked over, or mechanically tilled to put it in a loose condition, and lightly watered a day or two in advance.

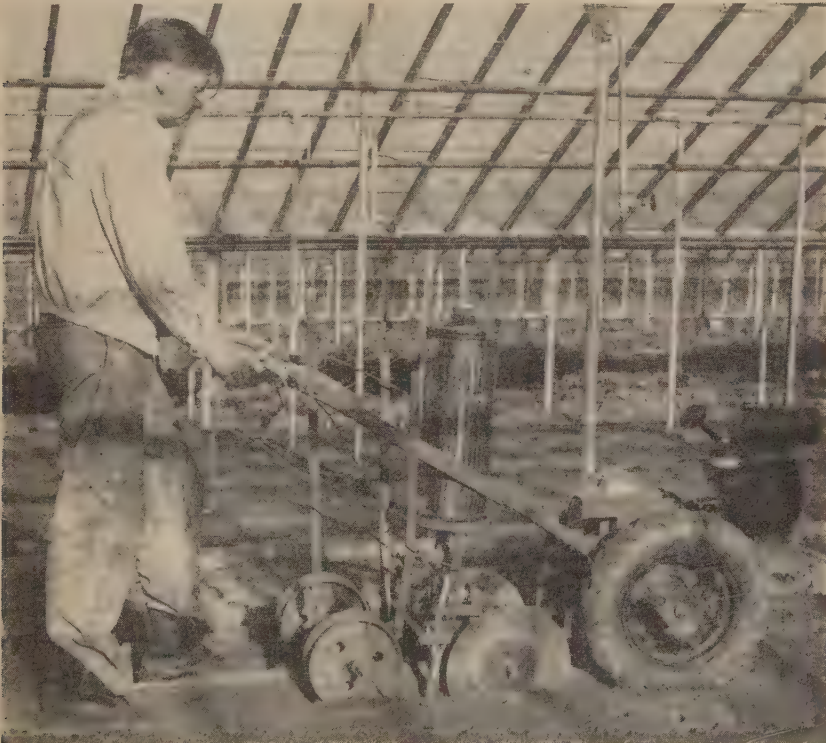
The dosage rates on 10-inch centers with injections 4 to 5 inches deep, for mixtures containing 10 to 15 per cent methyl bromide, are 5 to 7 ml. For chloropicrin and mixtures containing 10 per cent ethylene dibromide or any dichloropropenes, a dosage of 2 to 3 ml is recommended for each injection; for double-strength ethylene dibromide mixtures, one-half the above amount should be used. The holes made by the injector should be stepped on to close them. A water seal should be applied promptly after using chloropicrin or methyl bromide mixtures, and is optional with the others.

Several comparisons have been made between the injection method of applying methyl bromide mixtures and the continuous-drip method of subsurface application. In each instance the control of nematodes was much better by the injection method. Presumably this difference was due to the more prompt and effective sealing and confinement of the gas afforded by stepping promptly on the injection holes. With none of the smaller, tractor-operated, continuous-flow applicators was a comparable amount of pressure ever applied to the surface of the soil where the fumigant was injected (figure 6). The same relative efficiency of the two methods of application has been seen when chloropicrin has been applied in certain instances. This leads to the recommendation that hand injectors be used wherever feasible. If not feasible, the dosage rates of chloropicrin and the methyl bromide mixtures given above should be nearly doubled, and the surface of the soil should be moistened before, as well as immediately after, making the

application. It is probably advisable, with continuous-flow mechanical applicators, to liberate the fumigant 6 to 8 inches deep rather than 4 to 5, as recommended for hand applications. Rolling soil with a 200-pound lawn roller after treatment and before watering did not improve the control of nematodes in two greenhouse experiments with methyl bromide mixtures on light sandy soil near Rochester. Delay in application of the water seal for more than 15 minutes after hand applications were made reduced the effectiveness of the fumigant in some of these soils. It is possible to loosen the surface soil too much for best retention of gas. When mechanical tillage tools are used it is recommended that the soil receive a good watering and a rest for two or three days to firm it before treatment is made.

Radishes or beets sown for greens are recommended as good crops to follow fumigation since they are tolerant (or shallow-rooted), can be safely sown sooner than some other plants, and do fairly well in cool soil. Potted cucumbers are among the less tolerant, and potted tomatoes are intermediate.

Figure 6. A gravity-feed, 2-row, self-propelled soil fumigator, suitable for higher-boiling, less-volatile fumigants containing ethylene dibromide, chloropicrin, or propene-propane mixtures.



How to Treat Field Soils

Nematodes are indigenous to many parts of New York State; they attack the roots of wild plants and of cultivated plants grown on virgin soils. The root-knot nematode may make carrots completely unmarketable or salable only for stock feed because of stubby, "prongy" malformations. Other crops such as lettuce, celery, melons, salsify, parsnips, snapdragons, and even onions are sometimes attacked. No method of reducing these losses in field soils except by growing some other crop, has been available to vegetable growers until cheap soil fumigants appeared on the market at a cost of less than \$60 an acre. With the discovery of the dichloropropenes and ethylene dibromide, either of which can be used at a cost of from \$40 to \$60 an acre, the vegetable grower can now get relief from this pest, and also from wireworms, with one application.

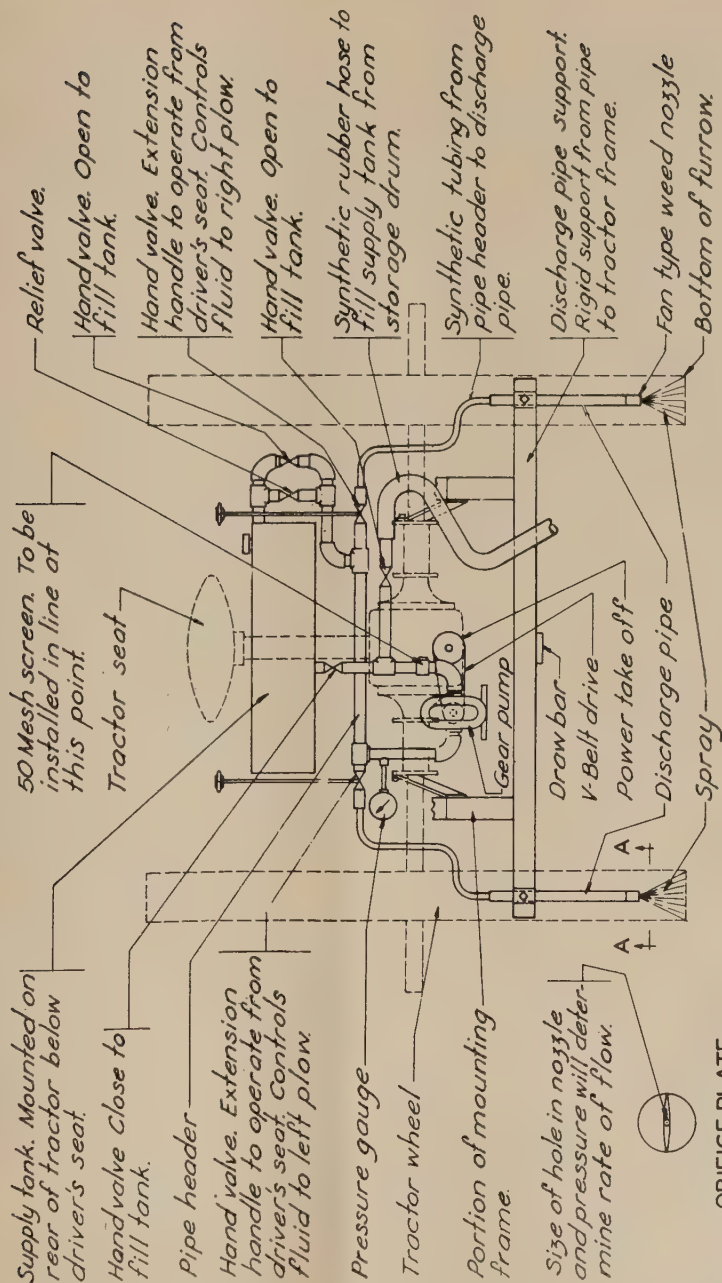
Two hundred and fifty to five hundred pounds (25 to 50 gallons) of either one of the dichloropropene mixtures, or a 10 per cent ethylene dibromide fumigant is recommended, the exact amount depending upon several local factors such as the extent of the infestation, whether soil is mineral or muckland, the crop to be grown, and whether a spring or fall treatment is planned. Products containing 20 per cent of ethylene dibromide may be used at half the above dosage rate. Since no water seal is required and the volatility is such that subsurface applications by multiple-row, tractor-drawn equipment are successful, the way is open to treat large fields far from available water supplies. Muckland soils demand heavier dosage rates than do sandy loam soils; likewise, the heavier rates are indicated for deep-rooted crops, dry soil conditions, and early fall applications.

The soil must be prepared by plowing and harrowing as in the preparation of a good seedbed. Discing alone seldom fits the soil to a sufficient depth if a deep-rooted crop such as parsnips, salsify, or carrots is to follow the fumigation. Sufficient time should elapse after plowing to permit rotting of trash if possible to avoid undue trouble from its accumulation on the shanks of the fumigator.

Types of Equipment for Field Treatments

A number of types of power-driven applicators have been built and are being used in various parts of the country. One of the cheapest is simply a tank mounted on a farm tractor with one or more tubes directing the solution down to the ground in front of the plow or plows. A tube every 8 to 12 inches, depending on the width and number of the plows, seems to be adequate for wireworm control under western conditions. This type of equipment has been described in *Soil Fumigation by Means of an Attachment to the Plow* (United States Department of Agriculture, Bureau of Entomology, Mimeo Leaflet ET-236). Prompt harrowing of the soil after plowing and treating is advised, to

GENERAL PLAN OF PLOW APPLICATOR FOR APPLYING SOIL FUMIGANTS



ORIFICE PLATE
VIEW A-A

REAR VIEW OF TRACTOR

break up any lumps and to compact the soil evenly. Although it has not been sufficiently tested for nematode control under New York conditions, the plow attachment may be the cheapest and most satisfactory piece of equipment for some growers (figure 7, lower).

From the experience on the West Coast, where the greatest progress in design and use of large-scale fumigating equipment has been made, the establishment in New York State of specialists with portable power-driven equipment, who will travel about and fumigate soil on a custom basis, seems likely. For such equipment the essential features of design may be outlined as follows: Trailer models are drawn by tractor (figure 11). Power to force out the fumigant may be obtained either from the power take-off shaft or from an independent gasoline engine. For

Figure 7. Upper: multiple-shank forced-feed fumigator attachment for tractor.

Lower: gravity-feed, double-lead attachment for a plow. (Photographs from Shell Development Corporation.)





Figure 8. The small (Gibson) tractor mounted on 3-row fumigator applicator used in New York experiments in 1947, loaned by Shell Chemical Company. A 5-gallon portable tank from which fumigant is siphoned is set out in front. The step drag behind is not shown in picture. See cover.

many small fields in this State such equipment may be a little too long, although its big advantage is that it does not tie up the tractor with cumbersome equipment. Smaller, more compact units can be mounted directly on tractors of any size (figures 7, 8, 9). These are probably the most practical for New York conditions.

The tractor should move forward at a constant speed which has been accurately measured and can be maintained by a governor. The fumigant is generally forced into the ground under a constant pressure maintained by a small gear pump having an automatic by-pass. The small brass gear pumps used so extensively for spraying carrots for weed control are fairly satisfactory when provided with pressure gauges and overflow returns. The pressure need not be high; one of 25 pounds has been found very satisfactory. The pump can be connected to whatever motor propels the tractor by means of a sliding V belt or other type of clutch. The fumigant is generally pumped from the supply tank, which may be carried in some convenient place on the tractor or the trailer; sometimes the tank is mounted above the pump so that gravity keeps the fumigant supply flowing.

With a constant forward speed and a constant pressure on the fumi-

gant, the rate of application can be regulated by placing discs with accurately bored orifices in unions in the lines between the pump and the outlets. These discs should be made of monel metal to resist the corrosive action of some fumigants. The hole sizes most frequently used are 30 to 40 thousandths of an inch, at line pressures of 20 to 30 pounds, with shank spacings of 10 to 12 inches, and at tractor speeds of 200 to 400 feet per minute. One side of the orifice hole should be bored concave, and should always be placed with this side away from the pump.

A good screen strainer must be placed in the suction line running to the pump.

There should be a pressure-control valve on the by-pass, closing of which gradually increases pressure on the outlet lines. When once set at the proper place this will not be used often, but it is very useful in calibrating a machine, or in changing, within limits, the rate of application.

A pressure-relief valve should be mounted on the discharge side of the pump to protect pump and piping if orifices should ever become clogged. This valve may be set to open at 50 to 75 pounds pressure.

Since some fumigants, such as DD mixture, are rather corrosive, all piping and tubing should be of brass, copper, or one of the synthetic rubbers, such as Saran or Resistoflex. The ends of the tubing can be flared with tools used by refrigerator repairmen in flaring copper tubing. No water should ever be permitted to enter the equipment if DD mixture or Resistoflex tubing is used; water makes DD more corrosive and will soften Resistoflex.

The fumigant is injected into the ground through copper tubes welded to the narrow rear edges of spear-pointed shanks. These in turn are mounted on a tool bar in the rear of the tractor or trailer, which can be raised and lowered with a lever operated by the driver. If a

Figure 9. A series of fumigation plots on sandy loam, showing one untreated check in the foreground, three treated plots in center, and another check halfway down the field, at Rochester, New York. (Figure 10 shows carrots from two of these plots.)



spring-loaded type of shank or a light spring shank is available, buried obstructions will cause less trouble.

A heavy wooden step-drag or its equivalent should be provided some distance back of the shanks to gather enough topsoil to seal the channels made by the shanks, and thus retard the escape of the gas.

The best distance apart for the shanks is probably 10 inches, depending on type of soil, moisture, temperature conditions, and fumigant used. Seldom should they be farther apart than 12 inches. When soils are heavy, tight, and cool, 8 or 9 inches is preferable, but in lighter soils or where infection is not severe 10 to 12 inches may be adequate. Soil moisture should be plentiful for best results (10 to 20 per cent on dry-weight basis for a sandy loam), which means good moisture for prompt seed germination.

Calibration of a trailer or tractor-mounted applicator

Some growers will wish to build their own soil fumigators. Suppose, for example, one wishes to apply 30 gallons of some fumigant per acre by means of 6 shanks spaced 10 inches apart on a tractor traveling 3 miles an hour. One should first determine what this dosage rate means in terms of milliliters (cu. cm, or cc) per linear foot per shank. Since there are 43,560 square feet in an acre (or 6,272,640 square inches) if the acre were in one long strip 12 inches wide it would be 43,560 feet long, and if only 10 inches wide it would have to be 52,272 feet long. There are 3785 ml in a gallon, so each linear foot must receive $30\text{g} \times 3785\text{ ml} = 2.17\text{ ml}$ of fumigant. Then, since there are 5,280

52,272 ft.

feet in a mile, at 3 miles an hour the rig in one minute travels forward $3\text{m} \times 5280\text{ ft} = 264\text{ feet}$. This means that the volume required per min-

60 min

ute for each shank must be 264×2.17 or 573 ml, and the total for 6 shanks will be 3438 ml per minute.

Table 2. Flow rates per minute for use in calibrating tractor-drawn, continuous-flow soil fumigators*

Speed of Tractor		Number of milliliters per minute required from each shank at 3 rates per acre and 3 shanks spacings										
		20 gallons			30 gallons			40 gallons				
		8"	10"	12"	8"	10"	12"	8"	10"	12"		
Miles per hr.	Feet per min.	2.00	176	204	255	306	306	382	459	408	510	612
2.50	220		255	318	382	382	477	573	509	636	764	
3.00	264		306	382	459	459	573	689	612	764	918	
3.50	308		357	445	535	435	668	803	713	890	1070	
4.00	352		408	510	612	612	764	918	816	1020	1224	
4.50	396		459	571	688	689	860	1034	917	1142	1376	
5.00	440		509	636	764	764	954	1146	1018	1272	1528	
ml needed per linear foot			1.15	1.45	1.73	1.73	2.17	2.61	2.36	2.90	3.47	

* Data in this table based largely on figures in *Soil Fumigation with Dowfume W-40* (Technical Agricultural Bul. Series, No. 5, published by Dow Chemical Company, Midland, Mich., April 1947).

Having determined the rate of flow necessary for the chosen dosage at the known tractor speed, the next step is to select the proper-sized orifice to use in each union just above the shank. From experience on the West Coast, it has been shown that an orifice of 0.037 inch, made with #73 drill will probably take care of dosages between 20 and 30 gallons per acre; dosages of 30 to 50 gallons can be delivered through an orifice of 0.0465 inch, made with a #56 drill at ordinary tractor speeds and at pressures of between 20 and 30 pounds.

Table 2 has been prepared to help in determining the proper flow rate of fumigant per shank, for three dosage rates per acre, with a number of different tractor speeds. The proper pressure to maintain on the pump to get the right delivery per shank per minute from a given set of orifice discs must be determined by actual trial with each individual machine. It is also essential to have each shank delivering the same amount. This calibration work should be done where ample ventilation is provided, using the fumigant that is to be applied. Water should never be used. The cleaning fluids used in spraying carrots may be fairly satisfactory for preliminary tests. A quick-opening valve is essential. In practice it is wise to find the amount delivered under 10, 15, 20, 25, 30, 35, and 40 pounds pressure for each set of orifices. With this information, together with that in table 2, and ability to drive the tractor at a known and constant speed, one can apply any desired dosage of a given fumigant.

There are certain sources of mechanical trouble that the operator should keep in mind. If the pressure gauge shows undue fluctuation the supply of fumigant may be low, the strainer may be clogged, the orifices may be plugged, dirt may have lodged under the seat of the relief valve, the belt may be loose, or the pump may need replacing. If the pump fails to deliver liquid, which is easily seen through the synthetic flexible tubing, it may need priming. For this an easily uncoupled union should be provided near the pump, where the pump can be primed. A priming cup may be placed in the line to simplify this process.

All unions on the discharge side should be of the large hand-operating type, and washers should be provided on both sides of the orifice discs.

Results of Field Tests for Nematode Control in New York, 1947

In the spring of 1947 comparisons between DD mixture and a 10 per cent ethylene dibromide fumigant (Dowfume W-10)² were made on three muckland and two upland vegetable farms where root-knot nematode had become a troublesome pest. Two rates of application were used, 200 and 300 pounds (20 and 30 gallons) per acre, and each rate was applied on 10- and 12-inch spacings of the delivery shanks at a depth of 6 inches. Four untreated checks were left, making a total of 12 plots on each farm. Soil temperatures were between 55 and 65°F. A three-row, tractor-mounted, continuous-forced-feed type of subsurface applicator was used, as shown in figure 8, page 19³. Growers prepared the land by plowing and disking. Treatments were made on May 12, 13, and 14. Carrots were sown across the plots about June 1 (figure 9, page 20). Unprecedented rains forced two growers to disc their fields and replant 10 or 12 days later.

During July, stand data were obtained on all five series of plots. These included the mean number of carrots and of weeds in 15 feet of row in each treatment; four such rows were counted in each plot. The results were variable, and showed that stands of carrots might be significantly improved or slightly reduced by either of these fumigants.

On one of the upland fields, mean stands were: 149 carrots in 15 feet of row on treated plots, and 129 on the checks, with odds of 99 to 1 that this was not due to chance. Since nematode damage to the roots on the check plots later in the summer was severe, it is believed nematodes were probably the cause of the reduction in seedling stands. This is supported by the fact that the carrot crop had been a failure on this field the year before, and by the further observation that it was a very favorable winter for carry-over of primary inoculum⁴. Weeds were not controlled well enough by either DD mixture or Dowfume W-10 to warrant recommending the treatment for this purpose. On one farm where weeds seemed to be very slightly reduced in numbers the carrot stands were affected similarly. A summary of the resulting stands of carrots is presented in table 3.

² Dowfume W-10 has recently been displaced by Dowfume W-40, which contains twice the quantity of active ingredient.

³ Loaned through courtesy of Shell Chemical Company. Fumigants supplied by Shell and Dow Chemical Companies respectively.

⁴ More nematode damage to seedling onions occurred on muckland in May and June than was ever recorded in the State before.



Figure 10. Upper: carrots from plots treated with the maximum rates of both fumigants. Lower: carrots from adjoining untreated plots.

tive. Yields of marketable carrots were approximately three times those of the check plots on the muckland, and five times on the upland, as a result of the fumigation. Control was not so good on the muckland as on sandy loam at the same dosage rates. It was therefore concluded that the maximum dosage rate (30 gallons) at the minimum spacing distance (10-inch) was the only one recommendable for a spring application on sandy loam with either material where nematodes are abundant. On muckland a still higher dosage might be desirable (40 gallons) were it not for the danger of "off" flavors to the carrots. This danger makes it seem desirable to suggest early fall applications on muckland of 40 gallons per acre, wherever possible, to give more time for dissipation of the gasses.

The results of flavor tests with carrots from treated plots revealed

In August, when the carrots had reached a size large enough for bunching, yield data were obtained from the five series of 12 plots over the State. Fifty carrots, pulled at random across each plot, were sorted in marketable and unmarketable (culls), and then weighed (figure 10). On many of the check plots more than half the roots were stunted, divided, misshapen, beaded, or "prongy," as most growers would call them. From table 4 it may be seen that DD mixture gave a little better control of nematodes than Dowfume W-10 used at the same rates. The 10-inch spacing was more effective than the 12-inch for DD, but not for the other fumigant. When the rate of application was reduced from 300 to 200 pounds per acre, control was not so effective.

Table 3. Mean stands of carrots per 15 feet of row on fumigated plots on five farms.

	Stands	
Check (20-plot mean)	79.3	
DD mixture at 200-lb. rate (10 plots)	72.7	} 77.7
DD mixture at 300-lb. rate (10 plots)	82.6	
Dowfume W-10 at 200-lb. rate (10 plots)	68.7	} 70.4
Dowfume W-10 at 300-lb. rate (10 plots)	72.1	
10-inch spacings (both fumigants)*	68.3	
12-inch spacings (both fumigants)	79.7	
200-lb. rate (both fumigants)	70.7	
300-lb. rate (both fumigants)	77.4	
L.D. for odds of 19:1	15.4	
	99:1 = 20.6	

* Excessive wind damage responsible for abnormally low stands on two plots.

that a few persons detected a slightly "soapy" or "flat" flavor in carrots grown on plots that had received the maximum amount of ethylene dibromide, and a slightly "bitter" flavor in those grown on plots that had received the maximum amount of DD mixture. Some "tasters" indicated carrots from the check plots as having the most undesirable "off" flavor, and some thought all the carrots tasted alike and satisfactory. Despite the fact that people vary in their capacity to detect flavors, the impression was left after flavor tests of carrots from all five farms were given to a total of 22 persons that there is a slight danger of an oily, flat, or even bitter flavor being imparted to carrots if too much fumigant is applied. This may also be true if, as occurred in

1947, too much rain falls too soon after the fumigant is applied. It would seem to be in the interests of the public, and the growers, that applications be made in the early fall whenever possible rather than in the spring, if a root crop is to be grown on soil treated with either of these fumigants.

Table 4. Yields of marketable carrots on fumigated plots

Treatment	Mean number marketable carrots*
Check (20-plot mean)	21.75
DD mixture at 200-lb. rate (10 plots)	41
DD mixture at 300-lb. rate (10 plots)	42.37
Dowfume W-10 at 200-lb. rate (10 plots)	38.1
Dowfume W-10 at 300lb. rate (10 plots)	40.1
10-inch spacings (both fumigants)	40.68
12-inch spacings (both fumigants)	40.75
200-lb. rate (both fumigants)	39.56
300-lb. rate (both fumigants)	41.8

* 50 is highest possible number of marketable carrots.

Least difference for odds of

19:1 7.74
99:1 10.29

Costs of Fumigating Soils

In a greenhouse, differences in cost of materials are probably not the primary consideration in the choice of fumigants. As shown in table 5, with an expenditure for fumigants of from 0.7 to 3.8 cents per tomato plant, several different chemicals used against root-knot nematode brought an increased return of from 19 to 26 cents per plant when tomatoes were selling at 25 cents a pound.

On a field scale, figuring at the lowest cost for materials, the two cheapest nematocides, containing either ethylene dibromide or dichloropropene, when applied at 30 gallons per acre will cost approximately \$40-\$50 an acre. When carrots bring a cent apiece and when yields of marketable carrots can be doubled by a treatment that controls nematodes, this expense is thoroughly justified (table 4).

Equipment for dribbling a fumigant into the soil while plowing has been assembled for as little as \$15. Hand guns for greenhouse use can be rented for \$1.00 a day, or purchased for less than \$30 apiece. Trailor-type multiple injectors are on the market in the West for as much as \$700.

In some States, soil fumigation is locally recognized as just as desir-

able a practice as liming or cover-cropping. A certain amount of government financial aid has been provided through incentive payments of up to 60 per cent of the cost of materials, in some places,

Table 5. Results of greenhouse ground-bed treatments for tomato-root-knot control, and value of treatments on a per-plant basis, 1943 fall crop, Auburn, New York.

Fumigant	Dosage on 10-inch centers	Mean root score*	Mean yield per plant	Cash income†	Cost to treat‡	Income Increased
	<i>ml</i>		<i>lbs.</i>	<i>dollars</i>	<i>cents</i>	<i>cents</i>
Check	0	2.81	4.54	1.13	—	—
Methyl bromide mixture (10%)	4.2	0.70	5.65	1.41	1.0	26.8
Methyl bromide mixture (10%)	6.2	0.67	5.38	1.34	1.5	19.5
Methyl bromide mixture (10%)	8.6	0.76	5.37	1.37	2.1	21.2
Chloropicrin	1.6	0.95	5.50	1.37	2.3	21.7
Chloropicrin	2.6	0.98	5.67	1.42	3.8	24.5
Propane-propene mixture	4.2	1.25	5.45	1.36	0.7	22.1
Least difference required for odds 99:1 ==		0.97	0.89			

* Five replicate plots of 20 tomato plants each, scored by system in which 0 means no galls; 1, very few small ones; 2, several; 3, an abundance; and 4 and 5, few to no healthy roots at end of picking season.

† Figured at 25 cents a pound as received by grower.

‡ For materials only.

or \$10 an acre up to 10 acres per farm in others. Total costs are chargeable to operation in figuring federal income taxes.

General Considerations

The fewer and smaller the lumps in any soil the better. A mechanical rotary tiller that pulverizes the top 6 or 8 inches puts most soils in a fine condition for fumigation. However, it is possible to have a ground-bed soil so loose that methyl bromide fumigants, in particular, escape too rapidly. If the soil is prepared a few days in advance and can be watered to aid in settling the top two inches, or if a cultipacker or roller can be used on it, the results should be more satisfactory. Plowing and deep discing have proved adequate for field soils, but dry periods may require rolling in addition. In greenhouses if manure is to be incorporated by digging in, this act will in itself prepare the soil for fumigation, although a light watering should precede the application to compact the surface.

Fields can be too dry, in which case 30 to 50 per cent higher rates per acre should be used. For best results soil moisture should be moderate to abundant, particularly for the propane-propene mixtures and the methyl bromide fumigants. High moisture, 15 to 20 per cent dry-weight basis in a sandy loam, gives much better results against fungi than does low moisture, 8 to 10 per cent. The theory is that microorganisms live and carry on their processes in a thin film of moisture, or at least in a very high hu-

midity, which exists around the soil particles. When this film, or humid air, becomes saturated with the toxic gas the microorganisms are poisoned. If there is too much water the toxic fumes can't pass freely through the soil to reach all the organisms, and if too little water, the gasses pass out of the soil too rapidly, so that contact between the organisms and lethal concentrations of the chemical is not maintained long enough.

Soil temperature has a marked effect upon all biological and chemical activity, and in general should be above 65°F when chloropicrin is used, unless one is willing to use an increased dose and let soil air a longer time. Soil can be down to 50°F when being treated with methyl bromide fumigants, the propane-propene mixtures, and the ethylene dibromide fumigants, although it may take three weeks for the latter two to escape. The dosage rate of methyl bromide mixtures in greenhouse benches and ground beds should be raised 10 or 20 per cent when such low temperatures prevail. In general, the quickest results at the dosage rates given will be obtained when soil temperatures are between 60° and 83°F and soil moisture is medium to fairly high.

Aeration of treated soil until all odor has left is imperative when chloropicrin, ethylene dibromide, or the propane-propene mixtures have been used. If soil treated with chloropicrin is brought back into a greenhouse where plants are growing before the aeration has been complete there is danger of burning the foliage or blooms on nearby plants. With methyl bromide mixtures there is almost no danger to living plants from the low concentrations used in soil fumigation. The authors have treated soil in ground beds in between rows of tomatoes 20 inches apart by injections of 7 cc of a 10 per cent methyl bromide mixture every 8 inches without any evident harm. Seeds of beets and radish have often been successfully sown 48 hours after treating ground beds with methyl bromide fumigants. In the propane-propene mixtures the odor is said to be due mainly to the higher boiling, less volatile trichlorides and so-called impurities in the mixtures, but they are rather toxic to plant life. The ethylene dibromide mixtures which have less pronounced odors, are, nevertheless, toxic to plant life, and treated soils should be thoroughly aired before being used.

The question of spring or fall treatments outdoors and what to use can be answered tentatively as follows. Most outdoor treatments in New York State will be made to control nematodes or wireworms, or possibly weed seeds. Where no water for sealing in the fumigant is available, and where economy dictates low-cost material at present, it will be either one of the ethylene dibromide fumigants or a propane-propene mixture. The ethylene dibromide mixtures are said to be a little more efficient

against wireworms than the propane-propene mixtures, and are certainly easier to handle; the latter seem to be slightly more effective nematocides at equal dosage rates (table 4). If onions or some other very early crop are grown in the spring, the treatment must be made in the fall before October 4. If carrots or some crop that can be sown as late as June 1 are to be grown, treatment can be made in either the fall or the early spring, whichever time is more convenient, although early fall treatments are advised.

Spacing of handmade injections 12 inches, 10 inches, or 8 inches apart each way makes a large difference in the amount of work done on an acreage basis, but in treating seedbeds, coldframes, benches, and small ground beds this extra work is not so important. There are approximately 100,000, 64,000, and 45,000 injections per acre when made on 8-, 10-, and 12-inch centers respectively. Since more thorough treatment is obtained by using the closer spacings and reducing the quantity per injection accordingly, the 8-inch spacing is advocated for seedbeds and small areas where seedlings or valuable plants are to be grown. The 10-inch spacing is advocated for most greenhouse work, especially with chloropicrin and methyl bromide mixtures and for most field work also.

A summary of the number of gallons required per 1000 square feet when injected at different rates at four different spacings may be found in table 6. For those who are buying materials by the gallon, table 7 will be found useful in estimating the requirements for different areas.

In storing soil fumigants it is best to keep them in a cool place. This is rather imperative with the methyl bromide mixtures, which may lose strength during the summer months at barn temperatures.

At the present time the authors do not feel that they can recommend the use of the soil fumigants mentioned in this bulletin for controlling symphyliids, cabbage club root, bacterial wilt, or fungus wilts caused by *Fusarium*, *Verticillium*, or the sclerotial-forming fungi, except as already noted in specific instances under treatment of small quantities of soil. Neither should field applications be relied upon to give very good control of weeds in most seasons, although occasionally exceptional results are obtained (figure 11, lower).

It is often questioned whether fumigation destroys earthworms and other useful soil organisms. The answer is that it does kill many of them, but populations soon build up again. There is a question in the minds of many as to how important earthworms are, since they are practically absent from two of the most productive soil types, the

Figure 11: Upper: a small trailer type of 4-row soil fumigator, loaned by Dow Chemical Company, used on sandy loam soil at Rochester, New York, in tests comparing Dowfume W-10 and DD mixture. At 400 pounds per acre with 10-inch spacing of shanks, applications made in September gave complete control of root-knot nematode on an early-spring crop of lettuce. On the check plots, plants had an average of 80 nematode galls.

Lower: weed control (mostly *Chenopodium*) with DD mixture was exceptional, as shown on left, and was less striking with Dowfume W-10, as shown on right. Check is barely visible on extreme right in distance.

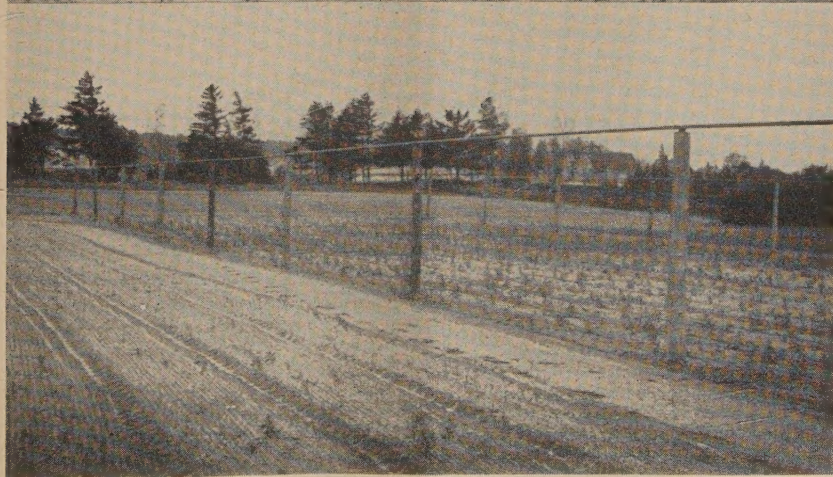
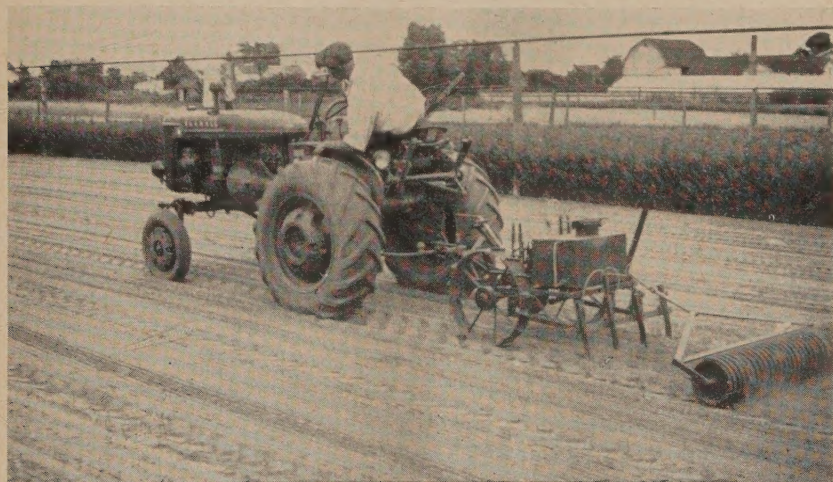


Table 6. Number of gallons of any fumigant required to treat 1000 square feet^{*}

At these spacings of injections	At these milliliters per injection						
	1	2	3	5	7	8	9
6 in.	1.06	2.11	3.17	5.28	7.40	17.74	9.51
8 in.	0.66	1.32	1.98	3.17	4.62	5.28	5.94
10 in.	0.40	0.79	1.19	1.98	2.77	3.17	3.57
12 in.	0.29	0.58	0.61	1.45	2.03	2.32	2.62

* Based on 4400, 2500, 1600, and 1100 injections at each of the 4 spacings indicated, which is approximately 10 per cent above the minimum theoretical numbers required. Experience has dictated that extra marginal injections are often advisable.

Table 7. Facts and suggestions to aid in the purchase and use of some fumigants tested by the writers to date.

Trade name	Pounds per gallon	MI per pound	Suggested dosage rates	
			per 1000 sq. ft. (gallons)	per acre (gallons)
Chloropicrin	13.8	273	1.0—1.3	40—50
Larvacide	13.8	273	1.0—1.3	40—50
DD mixture	9.9	378	0.7—1.0	30—40
Dowfume N	9.9	378	0.7—1.0	30—40
Garden Dowfume	7.1	530	1.5—2.	60—80
Dowfume W-40	8.9	428	0.4—0.6	15—20
Iscobrome D	7.7	494	0.7—1.0	30—40
Iscobrome	8.3	456	2.0—2.5	100
Dowfume G	11.3	334	2.0—2.2	90

Table 8. Some useful conversion measurements

Injections		
	per 1000 sq. ft.	per acre
On 8-inch centers	2450	100,000
On 10-inch centers	1600	64,000
On 12-inch centers	1100	44,500
Feet in a mile		5,280
Square feet in one acre		43,560
Square inches in one acre		6,272,640
Milliliters (cu cm) in 1 teaspoon (approx.)		5.0
Milliliters (cu cm) in 1 tablespoon		15.0
Milliliters (cu cm) in 1 fluid ounce		29.6
Milliliters (cu cm) in 1 pint		473.2
Milliliters (cu cm) in 1 quart		946.3
Milliliters (cu cm) in 1 gallon (U. S.)		3,785.4
Cubic feet of soil in 1 bushel		1.25

mucklands of western New York, and the sandy potato soils of Long Island.

Since most organisms soon find their way back into treated soils, one should not expect complete eradication of pathogenic forms from one

or two fumigations, no matter how carefully carried out.

Some growers still ascribe the benefits of soil fumigation to some sort of stimulation of plant growth. It seems more logical to the writers to assume that killing almost all nematodes, including the meadow nematode (*Pratylenchus pratensis*), results in great reduction in the number of minor root injuries of the sort that lead to root rots.

Some Precautions, Hazards, and Safety Measures

All the soil fumigants on the market contain as their active ingredient some volatile gas that is more or less poisonous. Some of them, such as chloropicrin and the propane-propene mixtures, give ample

warning of their presence, but others containing methyl bromide or ethylene dibromide have little or no warning odor. If they are handled outdoors, or if the period of exposure in a greenhouse or headhouse is not very long and is alternated with periods in fresh air, and if plenty of ventilation is always maintained, there seems to be no more danger in handling fumigants than in handling gasoline, explosives, or electricity. The proper technique must become a habit from the start. Some persons' skins may be more sensitive than others, and every precaution should be taken to protect the eyes against spattering liquid. If it does reach the eyes, plain water poured slowly into the open eye is advised as first aid until a doctor can be reached. Children must be kept away. Soap and water should be used copiously to rinse the skin. If spilled on shoes or on clothing in close contact with skin, their immediate removal is advised. The active ingredient dissolves in the fatty substances of the skin, or in some instances develops acids in the presence of skin moisture, and may result in burns, blisters, or other irritating complications. Often the first warning is pain around finger nails.

No jewelry should be worn when working with fumigants. Rubber boots and gloves are not always satisfactory protection, and, with methyl bromide fumigants are worse than nothing. The ethylene dibromide fumigants are the easiest and perhaps safest to work with. The methyl bromide mixtures are fully as easy to handle but the greater breathing hazard indoors must be kept in mind. The propane-propene mixtures and chloropicrin are corrosive to metals and rubber. In the presence of moisture, acids are formed so machinery used to apply DD, Dowfume N, or chloropicrin should be rinsed with kerosene or gasoline, followed by light oil, but water should never be used.

When injectors are built for use with the propane-propene mixtures, the following facts should be kept in mind. Galvanized metals and aluminum are not satisfactory, nor are synthetic rubbers, natural rubber, or neoprene. Monel metal and stainless steel are the safest metals to use; copper and brass are next. Furthermore, the presence of rust in time hastens decomposition of DD, resulting in the accumulation of sludge. The best substitutes for rubber hose at present are said to be "Saran" tubing and "Resistoflex," a poly-vinyl-acetate and poly-vinyl-chloride, respectively. Water will dissolve the latter, so in addition to care in rinsing, the tubing must be protected from rain.

If injectors are built for use with one of the ethylene dibromide mixtures, which are very much less corrosive, ordinary metals can be used and natural rubber tubing is the only thing to avoid, a poly-vinyl-acetate one being preferred. There is much less danger of decomposition and sludge formation, or of acid formation with ethylene dibromide mixtures than there is with the propane-propene mixtures.

Summary

During the past 10 years, the cost of fumigating soils for the control of nematodes and wireworms has been brought down to about one-tenth of its former amount.

The discovery of inexpensive fumigants that will kill these two pests without the necessity of being sealed in the ground for a period of time opens the way for treatment of large areas which hitherto it was not feasible to treat.

The newer fumigants, containing ethylene dibromide, or a mixture of dichloropropene and dichloropropane are unfortunately not nearly such good fungicides or herbicides as is chloropicrin, or even methyl bromide. The latter two materials have properties which still give them an important place in the control of several important pests in greenhouses and plant-propagating establishments.

Directions for fumigating small quantities of soil for damping-off and weed control with either chloropicrin or methyl bromide mixtures are given.

The use of these and the other fumigants in greenhouse soils for nematode and wireworm control is explained in some detail and the results of experiments in a vegetable greenhouse are given, which show that with the expenditure of from 0.7 to 3.8 cents per tomato plant for fumigants, an increased yield valued at from 19 to 26 cents per plant was obtained.

The results of field comparisons between DD mixture and one containing 10 per cent ethylene dibromide on five carrot fields over the State indicated that root-knot nematode could be controlled by applications of from 20 to 30 gallons (200 to 300 pounds) applied in continuous rows 10 or 12 inches apart and 6 inches deep, two or more weeks before sowing. When dosage rates were reduced to 20 gallons or spacing was increased to 12 inches, control was sometimes a little less effective. There was some reason to believe higher dosage rates for muckland than for sandy loam would be desirable, in which case early fall applications would be preferable because of the possible flavor that might be imparted to the carrots.

Descriptions of the essential features of some successful tractor-operated soil-fumigation equipment are given, together with specific directions for calibrating them. General precautions, and certain hazards involved in soil fumigation work are also discussed.